CONTROL VALVE CHARACTERISTIC
WCV 911

LEARNING OUTCOMES

1. To operate and demonstrate the operation of control valve plant
2. To sketch the major equipment, instrumentation, control infrastructure and controller
3. To classify the types of control valves
4. To calculate the $C_v$ of three control valve at various valve opening
5. To combine information for experiment from multiple sources
6. To facilitate use of modern data collection techniques (computer for data logging)
7. To share responsibilities with other team member
8. To share and provide information on time with others on the team
9. To combine different kind/source to create solution or new idea

INTRODUCTION

Pneumatic control valve is the most important final control element in the chemical process industry. Depending on the relationship between percentage flow and percentage flow control, valves can have different characteristics. Pneumatic control valves are air operated and hence a current-air transducer is required to convert the 4-20mA controller output.

EXPERIMENT A

AIM :

a) To determine and study the installed characteristics of three control valves that are installed in their respective piping system where more pressure drop is expected at the control valve than at the rest of the pipeline system.

b) To calculate the $C_v$ of three control valves at various Valve Openings.

CONTROL VALVES : FCVL, FCVE, FCVQ

SPECIAL REMARKS : Operate the smaller capacity pump PS through the three control valves one at a time, with its pipeline and manual valves fully opened for minimum pressure drop at the pipeline. FIC remains in Manual (M) mode. The control valves Positioners (PP) are connected.

KEY PARAMETERS : Flowrate (F), Valve Opening (Z or m), valve Pressure Drop (DPv), Pump discharge pressure (PGS). The input parameter is the valve input signal i.e. the control output MV from FIC in Manual (M) mode.
PROCEDURE


1. to 10. Please refer to the Section “START-UP CHECK LIST AND PRELIMINARY EXERCISES’ and follow the Procedures from 1 to 10. Please continue with the Procedures from 11 onwards.

11. Please refer to TABLE 1: OPERATION
This Experiment A requires only pump PS to be operated. Pump PB should be OFF. Its manual discharge valve MVB must be fully shut.

12. Do a quick check of the following.

   a) All the pumps suction valves are fully opened.
   b) Tanks T1 and T2 are filled with water almost up to the overflow pipe.
   c) The instrument air supply is connected and the air regulator (IAS) pressure is appropriately set.
   d) The main power supply is ON and the Controller FIC and Recorder FDPZR have lit up. FIC is in Manual (M) mode with its MV = 100% throughout this EXPERIMENT A.

13. Pump PS with the control valve FCVL at pipeline PLL:
    PS/FCVL/PLL, Position 1.
   a) Open fully the following manual valves:
      BVS, MVS, MVL1, MVL2.
   b) Shut fully the following manual valves:
      MVB, MVE1, MVQ1, BVL.
   c) For operation of FCVL, turn the Selector Switch SS1 to Position 1.
   d) Controller FIC must be in Manual (M) mode with its MV = 100%. Make sure the chart drive of the Recorder FDPZR is running. Otherwise press its ‘RCD’ pushbutton with its front swing cover opened.
A. Selection of Control Valve:
- Select Control valve below, either FCVL or FCVE or FCVQ
  i) Select the Selector Switch SS1 Positions to either 1, 2 or 3
  ii) Set up the Manual Valves as follows:

<table>
<thead>
<tr>
<th></th>
<th>Either FCVL/PLL</th>
<th>or FCVE/PLE</th>
<th>or FCVQ/PLQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open MVL1, MVL2. Shut MVE1, MVQ1, BVL</td>
<td>Open MVE1, MVE2. Shut MVL1, MVQ1, BVE</td>
<td>Open MVQ1, MVQ2. Shut MVL1, MVE1, BVQ</td>
</tr>
</tbody>
</table>

B. Manual Regulation:
- Use the Controller FIC to manually regulate the selected Control Valve
- Check that FIC is in **Manual (M)** mode. Start with MV at 100%.

C. Selection of Pump:
- Select pump to operate, either PS or PB
  - To operate PS: Open MVS, Shut MVB. Shut BVS fully after PS start up.
  - Note: Fmax*:
  - To operate PB: Open MVB, Shut MVS. Shut BVB fully after PB start-up.
  - Adjust MVB for similar Fmax* as in operating PB.

D. Recorder Usage:
- Use the Recorder FDPZR for Readings/Trend record.
- Check that the chart drive is running.

<table>
<thead>
<tr>
<th>Readings, engineering units</th>
<th>Trend/Trace record, analog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flowrate (F) : USGPM</td>
<td>Red pen, %</td>
</tr>
<tr>
<td>Valve Opening (Z or m) : %</td>
<td>Green pen, %</td>
</tr>
<tr>
<td>Valve Pressure Drop (DPv) : psi</td>
<td>Blue pen, %</td>
</tr>
<tr>
<td>Controller (FIC) Output (MV) : %</td>
<td>Violet pen, %</td>
</tr>
</tbody>
</table>

E. Pump Discharge Pressure:
- PGS, PGB for pump discharge pressure
- Pump not operating displays 0 discharge pressure.

- e) Start pump PS and verify its flow at the discharge of pipeline PLL into tank T2. Shut fully the pump by-pass manual valve BVS for maximum available flow through the control valve FCVL and the pipeline PLL using the smaller pump PS.

**NOTE THIS MAXIMUM AVAILABLE FLOWRATE Fmax (L)* FOR FCVL AT THE RECORDER FDPZR. SEE (f)**

(Please note down Fmax(L)*. Fmax (L)* will be required later for Experiment B, Procedure13 (e)).
f) Note the following readings at the recorder FDPZR and the pressure gauge PGS.
   Occasionally check that MV at FIC is the same as Violet pen (Channel 4) at
   FDPZR.

   g) Repeat (f) but this time, adjust the manual output of FIC by 10 to 20% at a
time, so that its MV is in decreasing (i.e. 100% to 0.0%) and then in increasing
   MV (i.e. 0.0 to 100%).

   h) Stop pump PS and proceed to test the next control valve as per Procedure 14.

The procedure is similar to 13 but for the proper switch, pump and manual valve
selection, please refer to Table 1: Operation for guidance

   NOTE THIS MAXIMUM AVAILABLE FLOWRATE Fmax (E)* FOR FCVE AT
   THE RECORDER FDPZR. SEE (f) BELOW.
   (Please note down Fmax(E)*. Fmax (E)* will be required later in Experiment B,
   Procedure 14(e)).

   f) Note the readings as in Procedure 13(f). Take note that the test is now on
   control valve FCVE using the smaller capacity pump PS.

   g) Repeat the above 14(f) but this time, adjust the manual output of FIC by 10 to
   20% at a time, so that its MV is in decreasing (i.e. 100% to 0.0%) and then in
   increasing MV (i.e. 0.0 to 100%).

   h) Stop pump PS and proceed to test the next control valve as per Procedure 15.

15. Pump **PS** with the control valve FCVQ at pipeline PLQ: **PS/FCVQ/PLQ**, Position 3.
The procedure is similar to 13 but for the proper switch, pump and manual valve
selection, please refer to Table 1: Operation for guidance

   NOTE THIS MAXIMUM AVAILABLE FLOWRATE Fmax (Q)* FOR
   FCVQ AT THE RECORDER FDPZR. SEE(f). (Please note down Fmax(Q)*.
   Fmax (Q)* will be required later for Experiment B, Procedure 15(e)).

   f) Note the readings as in Procedure 13(f). Take note that the test is now on
   control valve FCVQ using the smaller capacity pump PS.

   g) Repeat the above 15(f) but this time, adjust the manual output of FIC by 10 to
   20% at a time, so that its MV is in decreasing (i.e. 100% to 0.0%) and then in
   increasing MV (i.e. 0.0 to 100%).

   h) Stop pump PS.
16. To stop the Experiment and shut-down the model plant, please refer to the “SHUT-DOWN CHECK LIST” procedure.

Sample of results

<table>
<thead>
<tr>
<th>Adjust FIC Manual Output, MV %</th>
<th>Flowrate (F)</th>
<th>Valve Opening (Z or m)</th>
<th>Valve pressure drop (DPv)</th>
<th>Pump discharge pressure, PGS</th>
<th>Calculate the following ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Channel 1 USGPM</td>
<td>Red pen %</td>
<td>Channel 2 Green pen %</td>
<td>Channel 3 Blue pen %</td>
<td>(F/Fmax) * 100% % DPv/PGS</td>
</tr>
<tr>
<td>100.0</td>
<td>Fmax(L/E/Q)*</td>
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<tr>
<td>100.0</td>
<td>Fmax(L/E/Q)*</td>
<td></td>
<td></td>
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</tbody>
</table>

* There should be three tables for control valves FVCL, FCVE and FCVQ respectively

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EXPERIMENT B

The aim of the experiment is similar to the Experiment A with the same control valves and key parameters.

SPECIAL REMARKS : Operate the larger capacity pump PB through the three control valves one at a time, with the manual valve MVB manually regulated (i.e. shut slightly) so that the maximum available flowrate is the same as in Experiment A. The closing of the manual valve MVB is used to increase the pressure drop distribution at the pipeline i.e. increase DPL. FIC remains in Manual (M) mode. The control valves Positioners (PP) are connected.

The procedure (1 – 16) is similar to the Experiment A with special note on the respective valves.

Control Valve FCVL:
NOTE THIS MAXIMUM AVAILABLE FLOWRATE IS HIGHER THAN IN THE PREVIOUS EXPERIMENT A (13e) WHICH USES SMALLER PUMP PS TO PRODUCE Fmax(L)* FOR FCVL. PLEASE REFER TO EXPERIMENT A, PROCEDURE 13(e) AND (f), AND NOTE THE MAXIMUM AVAILABLE FLOWRATE (Fmax(L)* for FCVL) OPERATING PUMP PS (WITH MV = 100% AND BVS FULLY SHUT).
**Control Valve FCVE:**
DO A QUICK CHECK THAT THE **MAXIMUM** AVAILABLE FLOWRATE HERE IS HIGHER THAN IN THE PREVIOUS **EXPERIMENT A, PROCEDURE 14(e) AND (f)**. WHICH PRODUCES \( F_{\text{max}(E)} \) FOR FCVE USING PUMP PS.

READJUST THE MANUAL VALVE MVB UNTIL THE \( F_{\text{max}(E)} \) HERE IS THE SAME AS IN THE PREVIOUS EXPERIMENT A PROCEDURE 14(e), \( F_{\text{max}(E)} \) FOR FCVE USING PUMP PS. ONCE MVB IS ADJUSTED, DO NOT READJUST MVB AGAIN THROUGHOUT THIS EXPERIMENT.

**Control Valve FCVQ:**
DO A QUICK CHECK THAT THE **MAXIMUM** AVAILABLE FLOWRATE HERE IS HIGHER THAN IN THE PREVIOUS **EXPERIMENT A, PROCEDURE 15(e) AND (f)**. WHICH PRODUCES \( F_{\text{max}(Q)} \) FOR FCVQ USING PUMP PS.

READJUST THE MANUAL VALVE MVB UNTIL THE \( F_{\text{max}(Q)} \) HERE IS THE SAME AS IN THE PREVIOUS EXPERIMENT A PROCEDURE 15(e), \( F_{\text{max}(Q)} \) FOR FCVQ USING PUMP PS. ONCE MVB IS ADJUSTED, DO NOT READJUST MVB AGAIN THROUGHOUT THIS EXPERIMENT.

Sample of results

<table>
<thead>
<tr>
<th>Adjust FIC Manual Output, MV %</th>
<th>Flowrate (F)</th>
<th>Valve Opening (Z or m)</th>
<th>Valve pressure drop (DPv)</th>
<th>Pump discharge pressure, PGS psig</th>
<th>Calculate the following ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Channel 1 USGPM</td>
<td>Red pen %</td>
<td>Channel 2</td>
<td>Green pen %</td>
<td>Channel 3</td>
</tr>
<tr>
<td>100.0</td>
<td>F_{\text{max}(L/E/Q)}*</td>
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<tr>
<td>100.0</td>
<td>F_{\text{max}(L/E/Q)}*</td>
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</tbody>
</table>

* There should be three tables for control valves FVCL, FCVE and FCVQ respectively

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DISCUSSION
1) What is Control Valve Cv?

2) What is Control Valve Rangebility?

3) How is the control valve characteristics normally illustrated graphically?

4) The definition of the control valve inherent characteristics is qualified by the statement “at constant valve pressure drop”. How can the valve pressure drop be constant during operation when the valve is stroked from almost full shut to full open? DPv

5) What is the effect of DPv/DPs on the inherent control valve characteristics?

6) What is the effect of DPv variation from max DPv to min DPv on the inherent control valve characteristics?

7) Compare the characteristics curves of FCVL, FCVE and FCVQ obtained in Experiment A with those in Experiment B. Is the deviation from the inherent characteristics more serious in Experiment B than in Experiment A? Please comment on the DPv and DPs in each case.

8) Why is it important to know the control valve characteristics? Which is important finally in an operating control loop, the installed or inherent valve characteristics?
EXPERIMENT C

AIM : To test the effect of different control valve characteristics on PID Flow loop tuning.

CONTROL VALVES : The PID Flow loop consists of

a. FT-FIC-FCY-PP/FCVL

b. FT-FIC-FCY-PP/FCVE

c. FT-FIC-FCY-PP/FCVQ

SPECIAL REMARKS : Operate one Flow loop i.e. one pipeline at a time in Auto (A) mode at three different flow setpoint (SV) using pump PS. Then use pump PB but at the same maximum flowrate as using pump PS at its maximum flowrate.

KEY VARIABLE : The controlled variable is the volumetric flowrate measured by the Electromagnetic flowmeter FT.

PROCEDURES


1. to 10. Please refer to the Section “START-UP CHECK LIST AND PRELIMINARY EXERCISES’ and follow the Procedures from 1 to 10. Please continue with the Procedure from 11 onwards.

11. Please refer to the RESULTS section, TABLES 2L, 2E, 2Q to get an overview of the series of 18 tests to be performed with the Flow control loop, using one set of PIDvalues (PB1, T11, TD1), three different setpoints (SV) and two different pumps (PS andPB)

12. Do a quick check of the following.
   a) All the pump suction valves are fully opened.
   b) Tanks T1 and T2 are filled with water almost up to the overflow pipe.
c) The Instrument air supply is connected and the air regulator (IAS) pressure is appropriately set.

d) The main power supply is ON and the Controller FIC and Recorder FDPZR have lit up.
   - FIC is in **Manual (M)** mode with its MV = 100%.
   - The setpoint SV is at 15 USGPM.

13. **Experiment C1 - Flow Loop Tuning Tests with FCVL**

   a)  
      - Change the Selector Switch to **Position 1**, to select control valve FCVL for operation.
      - Switch FIC to **Manual (M)** mode and with its MV=100%, open FCVL fully
      - Shut fully manual valves MVE1, MVQ1, BVL but open fully MVL1 and MVL2.

   b)  
      - To operate only pump **PS**, shut fully manual valve MVB but open fully MVS and BVS (the manual by-pass valve of pump PS).
      - Start pump PS from the panel front pushbutton and verify its flow at the discharge of pipeline PLL into tank T2.
      - Shut BVS fully for maximum available flowrate through FCVL/PLL. Since FCVL is fully opened (MV at FIC is 100%), note this maximum flowrate **Fmax (L)** through FCVL from pump PS.

   c)  
      At SV = 15 USGPM, **Test 2L1 (FCVL/PS)**
      Check that the Flow Controller FIC is set as follows:
      PB1 = 100%; TI1 = 5 secs; TD1 = 0 sec
      Setpoint SV = 15 USGPM
      The PID values are set at the PID1 page/panel at FIC.

   d)  
      Check that the chart drive of the Recorder FDPZR is running.

   e)  
      Switch FIC to **Auto (A)** mode and observe the flowrate response (Red pen) patiently until it remains steady or it continues to oscillate for 3 cycles. Note the valve opening (Z or m) value from the recorder (Green pen). Is the response TOO SLUGGISH OR TOO OSCILLATORY, that RETUNING is required?

   f)  
      If necessary apply a **load step disturbance test** as follows: Switch FIC to **Manual (M)** mode, step increase or decrease its MV by about 20%, then quickly switch FIC back to **Auto (A)** mode and observe similarly.

   g)  
      Please refer to **TABLE 2L** at the RESULT section. This is Test 2L1, done with FCVL and PS at setpoint SV at 15 USGPM. Mark on the Recorder Red trend “FCVL/PS” and “15/100/5/0” (denoting the SV/PB/TI/TD values).
h) **At SV = 10 USGPM, Test 2L2 (FCVL/PS)** With FIC still in **Auto (A)** mode, step change its setpoint SV to 10 USGPM and observe the flow response (Red pen) similarly. If necessary, apply a load step test as in the previous (f). This is Test 2L2. Note also the valve opening (Z or m) at the recorder (Green pen). Mark on the Recorder Red trend “FCVL/PS” and “10/100/5/0” (denoting the SV/PB/TI/TD values).

i) **At SV = 5 USGPM, Test 2L3 (FCVL/PS)** With FIC still in **Auto (A)** mode, step change its setpoint SV to 5 USGPM and observe the flow response (Red pen) similarly. If necessary, apply a load step test as in the previous (f). This is Test 2L3. Mark on the Recorder Red trend “FCVL/PS” and “5/100/5/0” (denoting the SV/PB/TI/TD values). The chart responses are part of the results of this Experiment C. Note also the valve opening (Z or m) at the recorder (Green pen).

THE NEXT THREE TESTS WILL BE REPEATED USING PUMP **PB** WITH FCVL INSTEAD OF PUMP **PS**.

- Stop pump PS. Shut fully MVS.
- Open fully MVB, BVB.
- Switch FIC to **Manual (M)** mode and with its MV= 100%, open FCVL fully.
- Start pump PB and verify its discharge into tank T2 from pipeline PLL.
- Shut BVB fully for maximum available flowrate through FCVL/PLL.
- Manually regulate MVB until this maximum flowrate is equal to **Fmax(L)*** from the earlier Procedure 13(b) For the rest of Procedures 13 (j), (k), (l), do not readjust MVB again.

j) **At SV = 5 USGPM, Test 2L4 (FCVL/PB)** With FIC in **Auto (A)** mode, observe the flow response (Red pen) similarly. If further test at SV = 5 USGPM is necessary, apply a load step test as in 13(f), by switching FIC to **Manual (M)** mode, step changing MV by about 20%, and then switching FIC back to **Auto (A)** mode. Observe similarly. This is Test 2L4. Mark on the Recorder Red trend “FCVL/PB” and “5/100/5/0”.

14. **Experiment C2 - Flow Loop Tuning Tests with FCVE**

REPEAT THE SIMILAR PROCEDURE FOR EXPERIMENT C1 BUT ONLY WITH THE SELECTOR SWITCH AT POSITION 2.

15. **Experiment C3 - Flow Loop Tuning Tests with FCVQ**

REPEAT THE SIMILAR PROCEDURE FOR EXPERIMENT C1 BUT ONLY WITH THE SELECTOR SWITCH AT POSITION 3.
RESULTS – EXPERIMENT C1: Flow Loop Tuning Tests with FCVL

Use FCVL
Selector switch at position 1
PB1 = 100%; TI1 = 5 s; TD1 = 0 s

<table>
<thead>
<tr>
<th>Setpoint SV USGPM</th>
<th>Pump</th>
<th>*Observation with recorder chart response (Red pen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>PS</td>
<td>FCVL/PS, 15/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
</tr>
<tr>
<td>10</td>
<td>PS</td>
<td>FCVL/PS, 10/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
</tr>
<tr>
<td>5</td>
<td>PS</td>
<td>FCVL/PS, 5/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
</tr>
<tr>
<td>5</td>
<td>PB</td>
<td>FCVL/PB, 5/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
</tr>
<tr>
<td>10</td>
<td>PB</td>
<td>FCVL/PB, 10/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
</tr>
<tr>
<td>15</td>
<td>PB</td>
<td>FCVL/PB, 15/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
</tr>
</tbody>
</table>

NOTE* : At the OBSERVATION column, comment briefly on each test as follows:
A) Sluggish but acceptable. Retuning not required.
B) Oscillatory but acceptable. Retuning not required
C) Oscillatory. Retuning required BUT you do not have to retune this time

RESULTS – EXPERIMENT CE: Flow Loop Tuning Tests with FCVE

Use FCVE
Selector switch at position 2
PB1 = 100%; TI1 = 5 s; TD1 = 0 s

<table>
<thead>
<tr>
<th>Setpoint SV USGPM</th>
<th>Pump</th>
<th>*Observation with recorder chart response (Red pen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>PS</td>
<td>FCVL/PS, 15/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
</tr>
<tr>
<td>10</td>
<td>PS</td>
<td>FCVL/PS, 10/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
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<tr>
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<td>PB</td>
<td>FCVL/PB, 15/100/5/0 : Sluggish/Oscillatory/NoRetune/Retune</td>
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</tbody>
</table>

NOTE* : At the OBSERVATION column, comment briefly on each test as follows:
A) Sluggish but acceptable. Retuning not required.
B) Oscillatory but acceptable. Retuning not required
C) Oscillatory. Retuning required BUT you do not have to retune this time
RESULTS – EXPERIMENT C3: Flow Loop Tuning Tests with FCVQ

Use FCVQ
Selector switch at position 3
PB1 = 100%; TI1 = 5 s; TD1 = 0 s

<table>
<thead>
<tr>
<th>Setpoint SV USGPM</th>
<th>Pump</th>
<th>*Observation with recorder chart response (Red pen)</th>
</tr>
</thead>
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<tr>
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NOTE*: At the OBSERVATION column, comment briefly on each test as follows:
A) Sluggish but acceptable. Retuning not required.
B) Oscillatory but acceptable. Retuning not required
C) Oscillatory. Retuning required BUT you do not have to retune this time

Discuss the following:

1) Refer to the installed characteristics curves (i.e. % F versus % Z or m) from EXPERIMENT A and B for the three control valves FCVL, FCVE and FCVQ. For each curve, estimate the maximum and minimum valve gain Kv, within the region 5% to 95% Opening i.e. Max Kv, Min Kv. What is the implication of the ratio $\frac{\text{Max } Kv}{\text{Min } Kv}$ on the control response?

2) What is the overall Loop gain ($K_L$) of a control loop in terms of its loop components i.e. transmitter, controller, control valve, process? What can cause $K_L$ to vary?

3) From the 18 Tests conducted on the three control valves at different operating flowrates but using the same PID (i.e. controller gain $K_c$), comment on each test chart response as follows: A) Sluggish but acceptable. Retuning not required. B) Oscillatory but acceptable. Retuning not required C) Retuning required. Rationalise these comments with their corresponding valve characteristics curves and valve gain $K_v$. How should the PID be retuned?

4) When and why is loop retuning often required for the same control loop?

5) Consider the worst case scenario where the flow operating conditions (flowrates and setpoint) often changes and PID retuning is necessary. What options are available to avoid having to retune the loop